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# Building and Supporting Shared Understanding in Collaborative Problem-solving

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## Abstract

*Over the last decade the level of interest in the field of Computer Supported Cooperative Work (CSCW) has grown enormously to support various collaborative activities. Basically they all support argumentation in one or the other way. While many environments do support the process of bringing people into collaboration, the participants often fail to understand each others' activities, knowledge, beliefs or communicating contextual information. We propose an interface for the interactive construction of a Bayesian Belief Network for not only inferencing in uncertainty, but also for enhancing the deliberation of argumentation, and visualizing the insights of collaborative discourse to build and support shared understanding.*

## 1. Introduction

With the purpose of providing computer support for decision processes, be they formal or informal, specifically in the design domain (where success of problem solving sessions in the early stages of the project becomes critical in further actions to be taken), our area of interest falls under the category of design and decision support systems (DDSS). From the collaborative design and problem solving viewpoint, while most of the research in group decision support systems focuses on distributed operations [1], some others have addressed the problem of co-located operation [2], [3], [16]. This project focuses on the support for co-located synchronous operation (same-time/same-place) in a small group design problem-solving scenario. Argument visualization can be traced back to the *Chart Method* [17] which was used for analyzing the evidence presented in a legal case. In a chart, each numbered node has an explanatory entry summarizing the evidence. *The Uses of Argument* [18] describes the analysis of the logical structure of arguments leading to a graphical format. *Augmenting Human Intellect* [19] lays out a framework for enabling people to augment their intellectual faculties by manipulating externalized "concept structures". This pointed the way forward for computers as personal, intellectual aids, capable of updating flexible symbolic displays making possible a new coupling between one's thinking, and what was reflected back from the display [20]. A parallel stream of work goes under names such as *Concept Mapping* and *Mind Mapping* [21], [22] and both emphasize the "visual" as fundamental. The *argumentative design* perspective [23] motivated the development of Issue Based Information Systems (IBIS) [24] as a medium to encourage the open deliberation of issues. Visualized as a graph, the IBIS grows into a network with key entities as Issues, Positions and Arguments. Most of the first generation tools and methods force the crafting of arguments into linear form for visualization making it difficult to see alternate interpretations and points of view [25]. Subsequent researches motivated tools [26], [27] as a way to represent design argumentation explicitly, but with group process adding another dimension.

Recently, there has been a growing interest in the use of causal maps to represent domain knowledge of multi-disciplinary problem solvers [5], [28]. A causal map represents a decision maker's beliefs concerning the relationships between various factors of interest among team members. In a general sense, the goal of problem solving is to select the optimal of possible actions. In the collaborative view of problem-solving, the active participation of conversants is required to achieve sufficient grounding of the discourse [16]. Achieving a solid grounding or shared understanding in problem-solving strategies is the foundation of a systematic means for the support of collaborative design. Our research differs in the sense of not straight mapping of argument structures but visualization of ever changing dynamic situations that arise out of discussions in relation to individual as well as team beliefs and assumptions. We hypothesize that the collaborative and interactive process of constructing a Bayesian Belief Network (BBN) [10], [11] and visualizing the cases of interests will help build and support shared understanding. The idea is that problem solving is supported by the construction of a situation specific belief model in a synchronous interactive environment. We believe that the process of converting causal knowledge of team members into a belief network and

inferring those beliefs as an iterative and interactive process will not only help the team understand joint probability in terms of the solution but also build a shared understanding among the team by encouraging reasoning and communication.

## 2. Collaborative problem-solving and shared understanding

*Shared understanding* is an objected state achieved through interactive processes by which *common ground* between individuals is constructed and maintained. Any negotiation requires much shared information to be successful, i.e., mutual knowledge of beliefs and assumptions. This information is called *common ground* and conversational partners are constantly coordinating with each other to ground the content of their conversation. They try to elaborate the mutual belief that their partner has understood what they meant [12]. This is then called their shared understanding, which is assessed by a criterion that is agreed to be relevant for the current situation. To build shared understanding of each other's selected beliefs and interests in groups, participants not only hear each others versions but must also integrate such contributed pieces of work to understand the overall theme of the discussion. In a collaborative session, as an argumentation takes place, participants offer ideas, and make repairs or offer alternative descriptions in response to indications of lack of understanding [13]. Participants seek and provide evidence of understanding. Evidence is a contribution that a person makes during a conversation that both carries some content and assists the participants in establishing a mutual belief [15]. The development of common ground or shared understanding takes place as a continuous process through arguments, elaborating and reasoning on evidences constantly correcting and revising shared beliefs between the participants. The conceptual framework for building and supporting shared understanding can be described as follows.

The framework in Figure1 explains that every participant holds a set of beliefs and assumptions in a problem solving situation. Though this is a thin line of difference between the two, their differentiation is an important one in uncertainty. A *belief* can be defined as a degree of conviction of the truth of something especially based on a consideration or examination of the evidence. It is an awareness or understanding and knowledge. An *assumption* is accepted as true without proof. In a collaborative situation it can be seen as a requisition of knowledge from others. Two beliefs involved in an argument either result in an updated belief, a new belief or an assumption or remain in their initial state. An assumption which has turned into a belief can be seen as a proven assumption. *The Collaborative Problem-solving Space (CPSS)* that is currently under development will be described in more detail in the following section.

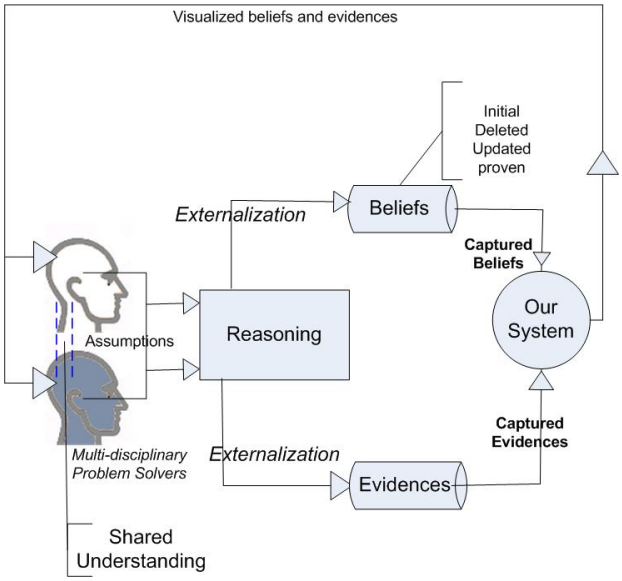


**Figure 1. Conceptual framework for building and supporting shared understanding**

### 2.1. The collaborative problem-solving space

As any place to set up collective activities, The Collaborative Problem-solving Space is primarily an environment for problem solving and decision making. The CPSS supports the process of converting causal knowledge of team members into a Belief Network and inferring those beliefs as an iterative and interactive process. This helps the team to understand joint probability in terms of the solution. It also supports the team to build a shared understanding by encouraging reasoning and communication. The CPSS supports requirements such as creation, transformation, relation, updation, and deletion of beliefs, assumptions and evidences. Here beliefs, assumptions and evidences are seen as the entities of the argument, those can be discussed upon. We regard annotations, images, drawings, sketches, movies and other artifacts used in the argument as evidence. The interface and interaction focuses on natural and direct manipulation techniques and tools.

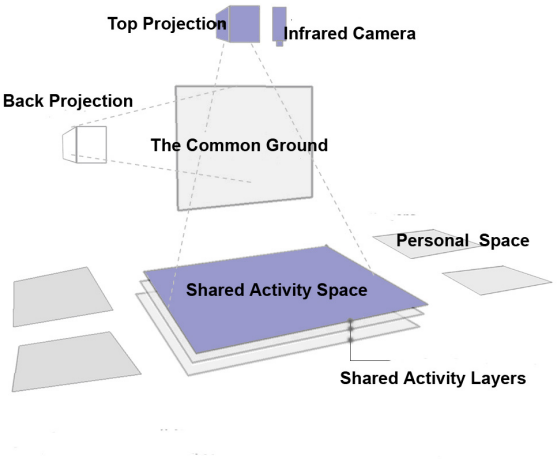


**Figure 2. Schematic representation of CPSS**

The CPSS can be divided into three spaces. They are, *Personal Space*, *Shared Activity Space* and the space for the visualization of belief structures that we call a *Common Ground*.

A *Personal Space* in the CPSS environment is the digital knowledge bank of an individual with supporting personal tools and data. It is also a place where individual beliefs are constructed and transferred into the shared activity space. The Personal Space is implemented by a Tablet PC with hand-writing recognition functionality.

The *Shared Activity Space* supports the basic negotiation, argumentation, and reasoning process. It is a space where knowledge is constructed, shared and acquired. This is the place where team members are interactively involved in causal mapping and construction of the belief network. The Shared Activity Space is composed of three layers of activity that support three stages of the process. The first layer supports the activity of elicitation and the second layer supports the activity of determining the causes and consequences. The third layer is used for the preparation and construction of the Bayesian network. The Shared Activity Space consists of original components from the Visual Interaction Platform (VIP) that was developed in the preceding research at Eindhoven University of Technology [6],[7]. The VIP uses a video projector to create a large computer workspace on the horizontal surface of a table. Projecting a computer display onto the surface of a table has been explored by many researchers [8],[9]. With the VIP system users can interact (perform their actions) using small physical blocks known as bricks. These bricks are coated with infrared reflecting material and there is an infrared light source located above the table next to the projector. A camera located next to the infrared light source and the projector tracks the movements of the interaction elements. The user interacts with the system by modifying the location and orientation of these bricks.

The *Common ground* is a dynamic visualization space. This space supports not only visualizing the current state of probability distribution of the problem situation and status in a team perspective but also helps in visualizing the process that took place in reaching the present status which is known as procedural context. Procedural context is extracted from the Shared Activity Space by triggering an event during negotiation and argumentation. The visualization scheme is under development.

## 2.2. Process of problem-solving in the CPSS

The process in the CPSS follows the line of inferencing. We classify three stages where Shared Understanding in a problem solving session becomes critical.

*Stage 1: Shared Understanding at problem definition stage.* At this stage most of the activity consists of identifying goals and objectives of the session and trying to figure out each other's interests. It is assumed that a certain level of shared understanding about the problem formulation is necessary and a team holds a certain amount of understanding on what they would like to discuss prior to the beginning of the session. This stage helps participants in understanding the team structure, selection of initial data and formulation of individual beliefs and mental models that might be used in the discourse.

*Stage 2: Shared Understanding at individual perspective stage.* This stage mainly deals with individual perspectives exchange. This level can be sub-classified into three stages. They are Elicitation, Elimination, and Externalization. In Elicitation, team members draw out the contextual knowledge to explicate a situation. In Elimination, team members try to merge concepts that are already having the same meaning and perspective. In Externalization members construct causal and consequential relations between issues and reason about them. We adopt a Causal Mapping technique to achieve that. Causal mapping refers to representing a set of causal relationships within a system. Causal mapping has the advantage of allowing team members to develop a shared representation for causality or situation.

*Stage 3: Shared Understanding at Team perspective stage.* Shared Understanding at the team level is to reflect on the combined effort and beliefs on the process that results in a situation described by a commonly agreed probability distribution.

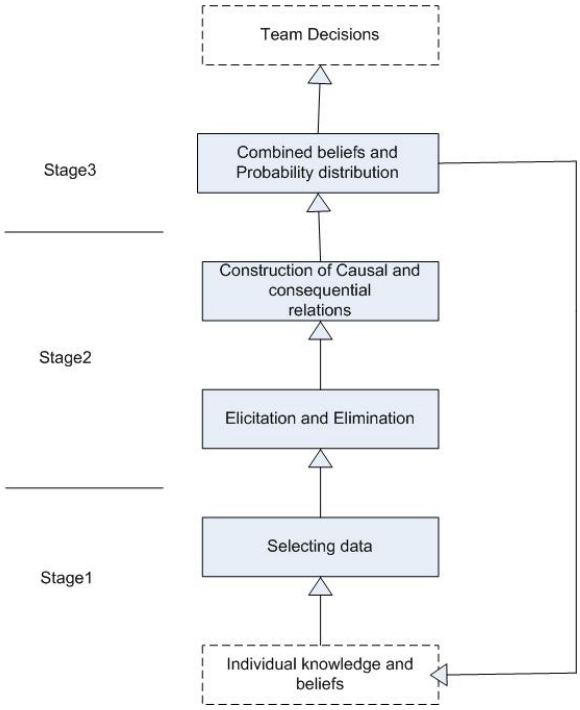


**Figure 3. Process in the CPSS**

## 3. A scenario

The following scenario illustrates the process and interactions in the CPSS. During the design of a tunnel project, a tragic accident happens in a recently finished tunnel of a similar construction type. Politicians require enhanced safety for all newly built tunnels. A team of eight tunnel design experts of a tunnel consortium and their client gets the assignment to redesign the entrance of a tunnel because of this sudden change in health and safety awareness. The time pressure is high: production is due to start in a few weeks! The team has only three days to redesign the entrance of the tunnel. The team has to prove that their new design fulfils the new regulations and is more valuable and cost effective than the original design.

After a short discussion and overview, members of the team had draw out a number of beliefs related to the problem from one's own perspective. They create beliefs in their personal spaces by scribbling on the tablet pc, and drag-and-drop [14] them into the shared activity space to share viewpoints. They are in the first layer of their shared activity space. Each dropped belief or assumption in the shared activity space becomes a node in the belief network later. After a short discussion similar interests are identified and merged by moving them on to each other using a reflective marker. Few beliefs are deleted by dragging issues into a trash bin situated at four corners of the space. Initially the team comes up with 15 beliefs and as the result of discussion they are down sized to 9 beliefs. Objectives and decisions to be made are identified. Visualization of interaction with beliefs is shown in figure 4(a) and initial beliefs on the common ground (the vertical display) are shown in figure 4(b). Interaction is established through direct manipulation using a digital pen and gesture input. Each of the beliefs on the visualization screen displays its title, name of the creator and other information graphically.

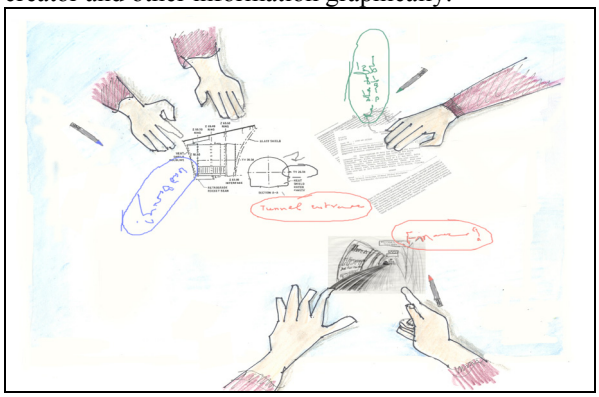

**Figure 4(a). Visual interaction with beliefs**

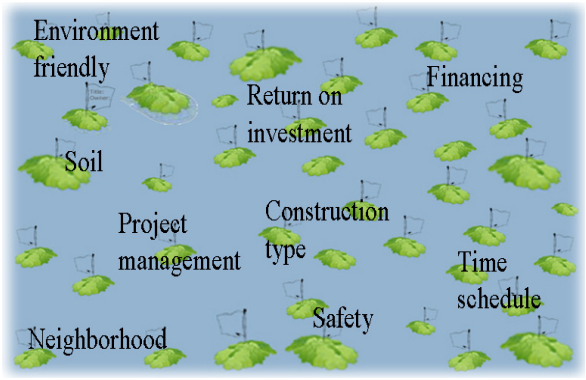


**Figure 4(b). Initial beliefs on the common ground**

Finally, 9 beliefs are transported to the second layer for reasoning and constructing causal and consequential relations. Each of the belief worth considering is specified as decision, nature, and objective nodes by simply selecting or entering information in a popup table (includes Conditional Probability Table (CPT) of the Belief Network in later use) using a digital pen. At this stage, every issue has become a node type with initial beliefs values. As the discussion progresses, team members reason out on their beliefs by attaching a supporting document to a belief. The supporting documents are obtained from personal space or created in the shared activity space. Whenever a belief is selected on the shared activity space, its evidence and contextual information is displayed on the Common Ground Space for visualization. As the next step team members identify causes and consequences and linked them by moving two issues very close to each other. A transparent arrow appears suggesting their

direction. All the connected nodes are transferred to the third layer to prepare for a Bayesian Network. For each belief evidence values are entered into CPT tables using a digital pen as shown in figure 5. The belief network is compiled by pressing a button. The resulting probability distribution is then visualized on the Common Ground. This result gives rise to new insights, new beliefs or agreements and the session is continued until the team is satisfied with the outcome of the session.

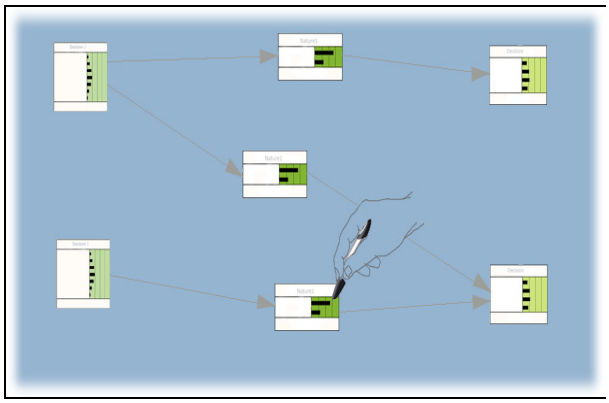

**Figure 5. Entering values into CPT using a digital pen**

## 4. Conclusion and future work

In this paper we discussed collaborative problem-solving and a procedure to build and support shared understanding during the discourse of a collaborative problem-solving session. We presented the conceptualized environment; the Collaborative Problem Solving Space and outlined the process. As the research project is in its initial stages, we are confined to present only the conceptualized space while other issues are under study. They are: developing techniques for extraction of procedural context, developing metaphors and a schema for visualization in shared understanding space, and a coding scheme for accessing shared understanding. At the moment, to support the stage 1 of the process, we are implementing the personal and shared activity spaces. We hope to report on this in the near future.


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